IMPACT OF SHOCK ABSORBERS QUALITY ON THE SAFETY OF CAR PASSENGERS AND CARGO

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Abstract

The analysis of impact of properly operating shock absorbers having a substantial influence on the vehicle safety is a main issue of this paper. A "Quarter-car suspension model" has been used in creating mathematic model for dynamic processes analysis – system of differential equations.

The dynamic processes taking place in the wheel suspension has been mathematically described using Quarter-car suspension model. A system of differential equations has been created and applied for programming Scilab Xcos. The results of modeling were verified by performing practical performance using automobile Volvo S80. The results of process modeling and practical car braking using shock absorbers of various quality evidently show the importance of their quality and significant impact on vehicle stability on the road. The simulation, applying Scilab X cos system allows to conclude that the mechanical oscillations during the braking process are quite significant (oscillation amplitude from 0.2, 0,1 m through 3 s period). In case of shock absorber malfunctioning the process simulation, when the damping force of the suspension system was 10 times reduced, the amplitude of moving masses grows up about twice and the period of oscillations lasts more than 3,5 times longer. That allows us to predict that these parameters could expand a braking time up to 20% - 30%, thus affecting the wheel's clamping force and, at the same time, the wheel's adhesion to the road. These factors directly affect the length of the braking distance, as well as the stability of the car's movement in the turn. Because, the results of practical measurements, proved the shock absorbers quality influence on so important parameters like vehicle stopping time and distance, quite often defining the vehicle safety on the road it's reasonable to stress on the importance of more strict technical quality control of shock absorbers.

Key words: car suspension, spring constant, damping constant, braking distance, oscillation processes, lumped parameters.

Introduction

All wheeled vehicles inevitably face the problem of dynamic shocks to the body. This, of course, depends both on the speed at which the vehicle moves, and on the road on which the vehicle is traveling, the smoothness and straightness of its surface. In particular, the efficiency issue of the wheel suspension design arises in car transport, because here the average speeds of traffic flows are growing most rapidly – it is dictated by the rapidly developing economic needs of various areas of logistics and the progress of innovations in technologies and, specifically, car construction nodes. [1]. However, it has to be admitted that one of the car's advantages is that the road on which it moves has much lower requirements than e.g. for railway transport, where, by the way, the dynamic forces acting on the cargo are of a different nature. On the other hand, the aforementioned lower requirements lead to inevitable road irregularities and turns, which during the movement of vehicle cause dynamic loads on the car body, which are transmitted to the cargo or passengers, and most importantly negatively affect the movement trajectory and its length (in case of braking). To neutralize dynamic loads (shocks), mechanical, hydraulic or mixed wheel suspension systems are used, the purpose of which is to at least partially absorb road shocks to the car body. [3] From the other hand the reaction of the car body, mentioned above, when affecting on movement trajectory, could significantly influence on traffic safety in general. The purpose of this study is to evaluate the processes taking place in the modern car suspension, individual nodes, i.e. the interaction between the spring and the shock absorber, as well as the influence of the suspension's performance, especially the shock absorber's functionality, on the car's movement, specifically on the quality of the braking process. It is also worth paying attention to the lack of technical control measures for shock absorbers when assessing the technical condition of the car during their regular inspection.

Problematic research questions set in the article: How intensive and how long lasting are oscillations of masses in car suspension system? How the quality drop can affect car stability on the road and how it could extend a braking distance of the vehicle?

The aim of the research - to define theoretically an impact of shock absorbers quality changes on oscillation processes of masses in car wheel suspension model and to verify practically the scale of this impact on vehicle dynamic stability and braking distance.

The objectives of the research:

1. Mathematically describe the dynamic processes taking place in the wheel suspension.
2. Perform simulation of dynamic processes occurring in the wheel suspension using the parameters of a real Volvo S80 car with the Scilab Xcos system.
3. Practically verify the results of modeling during car braking tests in two variants - a) when new, high-quality shock absorbers are installed in the suspension of the front axle, b) when elements that technically without shock absorbing elasticity are installed.

The methods of the research

In order to evaluate objectively the influence of the shock absorber on the dynamics of the car wheel suspension, the Quarter-car suspension model was applied, when a system of differential equations is created, and it‘s solutions show the influence of the quality of the shock absorber on the oscillating transient processes. Process results were obtained using the simulation program Scilab Xcos. [13]

Experimental part of the study - Seeking to verify the results practically during car braking tests (perform 20 brakes for each braking value, taking the average of their values) in two variants - a) when new, high-quality shock absorbers are installed in the suspension of the front axle, b) when elements that technically do not have shock-absorbing elasticity are installed. Objective evaluation of the impact of a car's shock absorber on the dynamics of the wheel suspension, allowing to assess the impact of high-quality shock absorbers on the car‘s dynamic stability.

Car wheel suspension and the processes taking place in it

In order to analyze the dynamics of car movement on the road, it is appropriate to choose the so-called "Quarter-car suspension model" often used by this field researchers. “Refer to Figure 1”.

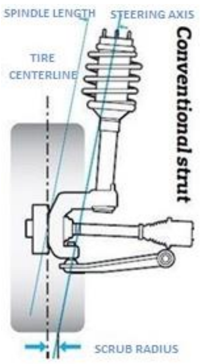

Figure 1. *Quarter-car suspension model. [1]*

Quarter-car suspension models are used to study the dynamics of a vehicle’s suspension. The model consists of: the wheel, the suspension system (damper and coil) and a quarter of the vehicle’s body mass.

The modeling approach is to use lumped parameters, which means that a quarter of the vehicle body and the wheel are concentrated in distinct single mass parameters. The stiffness and the damping of the suspension and of the wheel are also concentrated in lumped parameters. “Refer to Figure 2”.

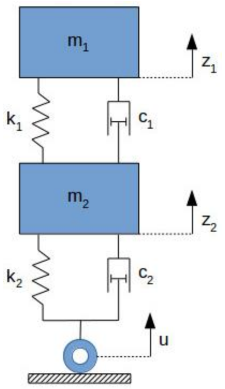

Figure 2. *Quarter-car lumped parameters model. [13]*

Where:
m_1 [kg] – the mass of a quarter of the vehicle body
m_2 [kg] – the mass of the wheel and suspension
k_1 [N/m] – spring constant (stiffness) of the suspension system
c_1 [Ns/m] – damping constant of the suspension system
k_2 [N/m] – spring constant (stiffness) of the wheel and tire
c_2 [Ns/m] – damping constant of the wheel and tire
z_1 [m] – displacement of the vehicle body (output)
z_2 [m] – displacement of the wheel (output)
u [m] – road profile change (input)

The road profile is considered to be the input into the system. The purpose of the study is to analyze the system's response (outputs) for a step input of the road profile, which can be regarded as the wheel going above a steep rigid object on the road (rock, brick, etc.)
Before writing down the equations, we need to draw the free body diagram (FBD) of the system. From this we will deduce the force equilibrium equations for both masses. Since there are two coupled masses, the dynamic system has two degrees of freedom. "Refer to Figure 3".

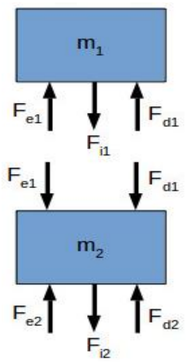

Figure 3. *Quarter-car free body diagram (FBD). [13]*

where:
F_{e1} [N] – the elastic force of the suspension system
F_{d1} [N] – the damping force of the suspension system
F_{i1} [N] – the inertial force of the vehicle body
F_{e1} [N] – the elastic force of the wheel and tire
F_{d1} [N] – the damping force of the wheel and tire
F_{i1} [N] – the inertial force of the wheel and tire

The directions of the forces are set according to the following reasoning. Imagine that the road has a bump and the wheel rolls over it. The profile change of the road will cause the tire to compress. This will generate an elastic force F_{e2} and a damping force F_{d2} which will push the wheel up. Due to inertia, the wheel will try to resist the position change through the inertial force F_{i2}. The elastic and damping forces are also acting on the road but this is not in the interest of our study.
The suspension system will oppose the upward movement of the wheel and it will push on it with the elastic force F_{e1} and a damping force F_{d1}. According to Newton's third law of motion, for each action there is a reaction. Therefore the elastic force F_{e1} and the damping force F_{d1} will push the vehicle body upwards. [7], [13]. Due to inertia, the body mass will try to resist the position change through the inertial force F_{i1}.

The equation of force equilibrium for the body mass is:

$$F_{i1} = F_{e1} + F_{d1} \tag{1}$$

The inertial force of the body, and the elastic and damping forces of the suspension system are expressed as:

$$F_{e1} = k_1(z_2 - z_1) \tag{2}$$

$$F_{d1} = c_1\left(\frac{dz_2}{dt} - \frac{dz_1}{dt}\right) \tag{3}$$

$$F_{i1} = m_1 \frac{d^2 z_1}{dt^2} \tag{4}$$

Replacing the expressions of the forces in equation (1), we get:

$$m_1 \frac{d^2 z_1}{dt^2} = k_1(z_2 - z_1) + c_1(\frac{dz_2}{dt} - \frac{dz_1}{dt}) \tag{5}$$

The equation of force equilibrium for the wheel mass is:

$$F_{i2} + F_{e1} + F_{d1} = F_{e2} + F_{d2} \tag{6}$$

The inertial force of the wheel, and the elastic and damping forces of the wheel system are expressed as:

$$F_{e2} = k_2(u - z_2) \tag{7}$$

$$F_{d2} = c_2(\frac{du}{dt} - \frac{dz_2}{dt}) \tag{8}$$

$$F_{i2} = m_2 \frac{d^2 z_2}{dt^2} \tag{9}$$

Replacing the expressions of the forces in equation (3), we get:

$$m_2 \frac{d^2 z_2}{dt^2} = k_2(u - z_2) + c_2(\frac{du}{dt} - \frac{dz_2}{dt}) - k_1(z_2 - z_1) - c_1(\frac{dz_2}{dt} - \frac{dz_1}{dt}) \tag{10}$$

The ordinary differential equations (ODE) (5) and (10) describe the dynamic behavior of the quarter-car model.

Before integration in Xcos, we need to keep on the left-hand side of the equal sign only the second derivatives of the displacements. This will give:

$$\frac{d^2 z_1}{dt^2} = \frac{1}{m_1}\left(k_1(z_2 - z_1) + c_1(\frac{dz_2}{dt} - \frac{dz_1}{dt})\right) \tag{11}$$

$$\frac{d^2 z_2}{dt^2} = \frac{1}{m_2}\left(k_2(u - z_2) + c_2(\frac{du}{dt} - \frac{dz_2}{dt}) - k_1(z_2 - z_1) - c_1(\frac{dz_2}{dt} - \frac{dz_1}{dt})\right) \tag{12}$$

Before building the Xcos block diagram model, we need to load the parameters of the system in the Scilab workspace or in the Set Context environment from Xcos.

```
m1 = 290;
m2 = 60;
k1 = 16200;
k2 = 191000;
c1 = 1000;
c2 = 2500;
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Based on the differential equations above we build the Xcos block diagram model: “Refer to Figure 4”.

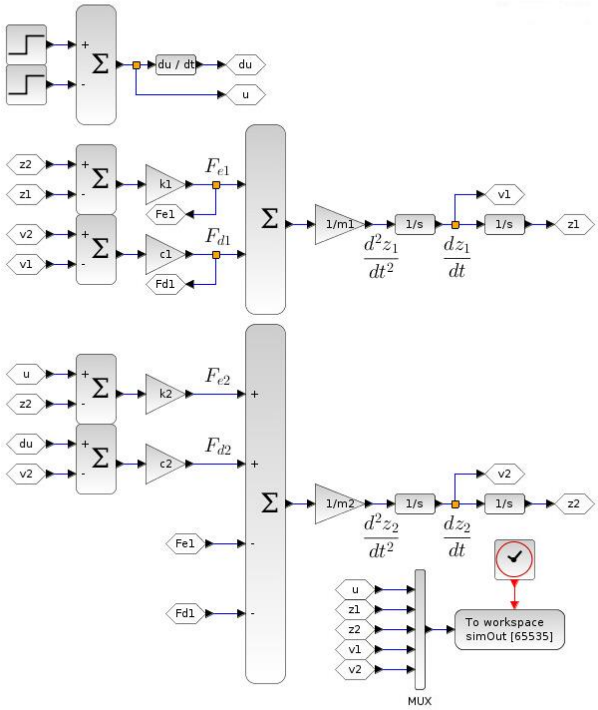


Figure 4. *Quarter-car Xcos block diagram model*

The road input u is modeled as a step input, with a rising edge and falling edge. v1 is the vertical translational speed of the body of the vehicle and v2 is the vertical translational speed of the wheel.
All the initial conditions of the integrators are set to zero. The simulation is set to run for 8 seconds. The results of the simulations are saved in the Scilab workspace, under the variable simOut. To plot the outputs we use the Scilab script.

Diagrams of the Volvo S-80 car braking transient process.The system's response is plotted in the graphical window below. “Refer to Figure 5, 6 and 7, 8”.

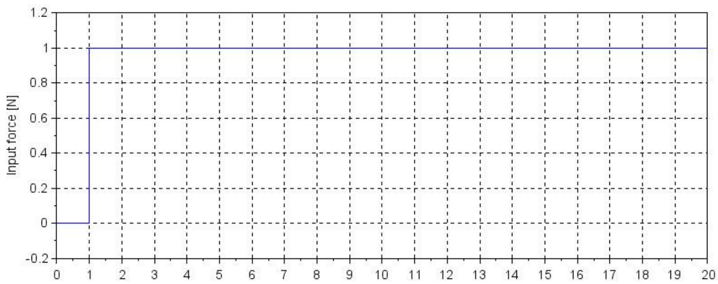
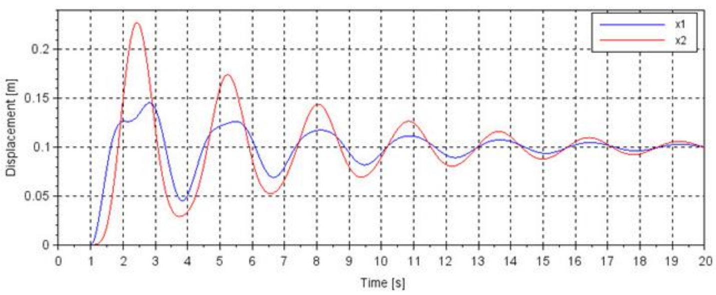
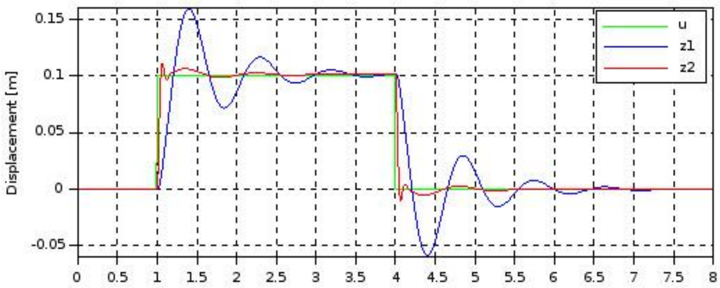


Figure 5. *System's response to step force input (force/time)*

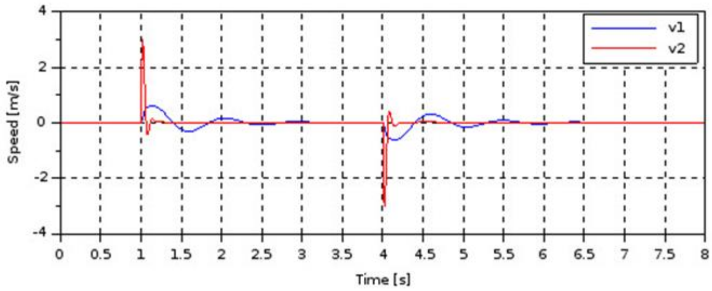


x1-vehicle body movement; x2- wheel movement.
Figure 6. *System's response to step force input (displacement/time)*



u-input movement; z1-vehicle body movement; z2-wheel movement.

Figure 7. *The system's response to double step force input is plotted in the graphical window (displacement/time)*



v1-vehicle body movement; v2- wheel movement.

Figure 8. *The system's response to double step force input is plotted in the graphical window (speed of masses/time)*

After the simulation, it can be concluded that the mechanical oscillations during the braking process are quite significant (amplitude from 0.2, 0,1 m through 3 s period), thus affecting the wheel's clamping force and, at the same time, the wheel's adhesion to the road. These factors correspond to vehicle braking time and directly affect the length of the braking distance, as well as the stability of the car's movement in the turn. To describe a case of shock absorber malfunctioning the process of simulation has been analyzed – i.e. the damping force of the suspension system was 10 times reduced. The amplitude of moving masses grew up about twice and the period of oscillations lasted more than 3,5 times longer. That allows us to predict that these parameters could expand a braking time up to 20% - 30%. It should be noted that during modeling we only get amplitudes and velocities of suspension mass oscillations, but the real path of the car depends on the adhesion of the road surface to the wheel, or on the coefficient of friction between them, but knowing what the suspension mass oscillation times and amplitudes are, it is possible to determine how much these factors influence braking process.

Practical measurements of the impact of the car shock absorber quality on real braking parameters

In order to determine the influence of shock absorber quality on real braking parameters, a technical experiment was conducted, during which the braking parameters of the Volvo S80 car were fixed. i.e. braking distance and braking time when the initial braking speed was 20 km/h, 40 km/h and 60 km/h until full stop. The second part of the experiment was carried out by measuring the same parameters after the shock absorbers of the car's front wheel suspensions has been replaced with analogous mechanisms without elasticity. According to results of mathematical modeling, we know that the time of oscillations increases by more than 2 times, and the oscillation amplitude practically does not die out, so the braking distance should be significantly longer – it should reach 20%-25% higher values (because shock absorbers has been removed from front suspension). It is also true that it is impossible to avoid the shock-absorbing or oscillation-quenching effect completely, because the wheel tire partially suppresses the oscillations by tire rubber springing.

The results of the practical effect of shock absorber quality on real braking parameters are presented. "Refer to Table 1 and Table 2".

Nr.	Initial braking speed [km/h]	Stopping time [s]	Stopping distance [m]
1.	20	1,18	2,28

2.	40	1,54	9.93
3.	60	2,36	21,04

Table 1. *Parameters of the braking process when all 4 shock absorbers are of good quality:*

Nr.	Initial braking speed [km/h]	Stopping time [s]	Stopping distance [m]
1.	20	1,41	2,75
2.	40	1,86	11,98
3.	60	3,12	27,12

Table 2. *Parameters of the braking process when the shock absorbers of the front wheels are of poor quality:*

Note:

Measurements of the parameters of the braking process were carried out during the measurement of each parameter in the table has been set performing 20 brakes for each braking value and taking the average of measured values.

The results of practical measurements, presented in tables 1 and 2 obviously show the influence on so important parameters like Stopping time and distance – increase for 18%-22%. These parameters very often define the vehicle safety. However, it’s reasonable to conclude that an owner of the vehicle is unaware about the real stage of shock absorbers because technical checking procedure doesn’t exist. Because the results of process modeling and practical car breaking highly correspond to each other it’s reasonable to conclude the importance of more strict technical quality control of shock absorbers.

Conclusions

1. The dynamic processes taking place in the wheel suspension has been mathematically described using Quarter-car suspension model. A system of differential equations has been created.

2. After the simulation, applying Scilab X cos system it can be concluded that the mechanical oscillations during the braking process are quite significant (oscillation amplitude from 0.2, 0,1 m through 3 s period). In case of shock absorber malfunctioning the process simulation, when the damping force of the suspension system was 10 times reduced, the amplitude of moving masses grew up about twice and the period of oscillations lasted more than 3,5 times longer. That allows us to predict that these parameters could expand a braking time up to 20% - 30%, thus affecting the wheel's clamping force and, at the same time, the wheel's adhesion to the road. These factors directly affect the length of the braking distance, as well as the stability of the car's movement in the turn.

3. The results of process modeling and practical car breaking on Volvo S80 correspond to each other, so it confirms the hypothesis of the research.

4. It’s reasonable to conclude that usually a vehicle owner is unaware about the real stage of shock absorbers because technical checking procedure doesn’t exist. Because results of practical measurements obviously show the influence on so important parameters like vehicle stopping time and distance, quite often defining the vehicle safety on the road it’s reasonable to stress the importance of more strict technical quality control of shock absorbers.

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